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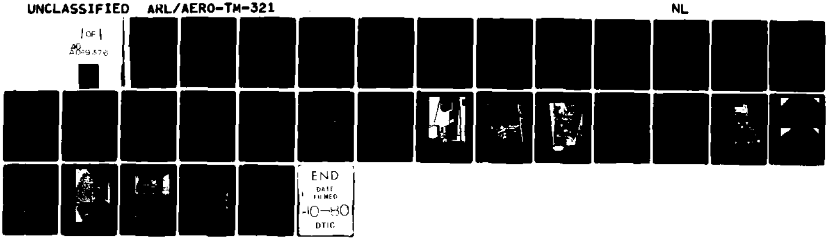

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DEPARTMENT OF DEFENCE

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AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

Aerodynamics Technical Memorandum 321

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N. POLLOCK

Approved for Public Release.

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OPERATING MANUAL FOR TRANSONIC WIND TUNNEL LASER INTERFEROMETER

N. POLLOCK

SUMMARY

This memorandum describes the setting up and operation of the ARL transonic wind tunnel laser interferometer. Notes on suitable tests for interferometric investigation and interferogram analysis are also included.

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A

SAFETY NOTE

EXPOSURE TO RADIATION FROM THE CR-4 LASER USED WITH THIS INTERFEROMETER CAN PRODUCE SKIN BURNS AND PERMANENT DESTRUCTION OF VISION. ONLY PERSONNEL SPECIFICALLY AUTHORISED BY THE TRANSONIC AERODYNAMICS GROUP LEADER MAY USE THE EQUIPMENT AND ALL PRECAUTIONS MUST BE TAKEN TO PROTECT OPERATORS AND CASUAL PASSERS-BY FROM ACCIDENTAL EXPOSURE. THIS PROBLEM IS PARTICULARLY ACUTE IN THE TUNNEL CONTROL ROOM SINCE IT IS ALSO USED AS A THOROUGHFARE.

1. INTRODUCTION

A new laser interferometer arrangement based on a conventional wind tunnel schlieren system was developed by the present author during 1977. This interferometer is thought to have significant advantages over other similar arrangements and a full description of the design along with test results from a prototype instrument is presented in Ref. 1.

A version of this interferometer specifically designed for use with the transonic wind tunnel 406 mm schlieren system has now (July 1979) been completed. The instrument has been used to record over 200 interferograms and can be regarded as part of the standard tunnel instrumentation.

In this memorandum the setting up and operation of the instrument are described in detail. Notes on the range of application of the interferometer and interferogram analysis are also included.

The reader's attention is drawn to the requirement for obtaining the group leader's authorisation before using the laser.

2. DESCRIPTION OF SYSTEM

The arrangement of the interferometer at the source (in "U" of tunnel) and receiving (in control room) ends of the system is shown diagramatically in Figs. 1 and 2 respectively. The laser, pockels cell, electro-mechanical shutter and spatial filter beam expander are mounted on a wooden structure which is supported by a tubular steel outrigger frame attached to the source schlieren box (Fig. 3). It is intended in due course to replace the wooden structure with a permanent metal frame. A laser power meter (Coherent Radiation model number 210) is mounted so that it can be conveniently interposed between the laser and the pockels cell. Inside the source schlieren box the reference beam focusing lens and additional plane mirror (Fig. 1) are mounted on an optical rail which is bolted to the floor of the box. The lens is supported by a five degree of freedom mount which is fabricated from Ealing-Beck components (Fig. 4). The schlieren light source components can be left undisturbed during interferometric operation and the additional interferometer components can be left in place during schlieren operation.

At the receiving end of the system, to convert from schlieren to interferometric operation, the knife edge must be removed and the reference beam expanding lens, beam folding mirror, camera lens and camera, inserted (Figs. 2 and 5). All the additional components mount on the existing optical rails. The reference beam expanding lens is supported by an identical mounting to the reference beam focusing lens.

A simple paper tube between the camera lens and camera is used to reduce the background light reaching the film to a level where normal control room illumination can be used during interferometer operation.

The laser modulation, and mechanical and electro-optic shutters are driven by a control unit which is triggered by the camera electronic flash synchronisation contacts. Circuit and timing diagrams for the control unit are presented in Figs. 6 and 7 respectively. The resistor-capacitor network on the flash synch. input is designed to suppress false triggering caused by electrical pick-up in the wiring connecting the camera to the control unit. In Fig. 8 a photograph of the control unit, the laser power meter and the high voltage pulse amplifier which drives the electro-optic shutter is presented.

The reasons for the use of the relatively complex laser output control system described above are as follows: It is known from previous work[1] that a laser output pulse a few microseconds long with a power of at least one watt is required to obtain good quality interferograms. The CR4 SG Argon ion laser was selected as the most suitable of the lasers available within the transonic tunnel group. This laser has an external modulation input which unfortunately, due to a bandwidth limitation of a few kilohertz, is unsuitable for the production of microsecond pulses. The preferred method of producing short pulses from a CW laser of this type is the use of an intra-cavity electro-optic Q switch. Unfortunately no suitable device was available from the laser manufacturer and the in-house development of such an arrangement was thought to be uneconomic. The method adopted involves the use of an electro-optic modulator in the laser output beam. Most available modulators have an extinction ratio of about 1000:1 and a one millisecond mechanical shutter was therefore added to prevent the modulator off state leakage exposing the film during the relatively long camera shutter open time required for flash synchronisation with a focal plane shutter. Neither the mechanical shutter nor the electro-optic modulator could safely block the full laser output power for long periods. Therefore the laser modulation input is used to produce 30 msec. bursts of laser output when an output pulse is required. The resulting arrangement, despite its complexity, has proved completely satisfactory in practice.

3. SETTING UP AND ADJUSTMENT

(a) READ SAFETY INSTRUCTIONS AND CHAPTERS 1 TO 3 OF REF. 2.

(b) Set up laser with single line mirror (model 434 wavelength selector) and adjust to maximise output in 514.5 nm green line (at least 1.5 W should be obtained).

(c) If the system is not already assembled; place the laser head, power meter head, electro-optic modulator, mechanical shutter and spatial filter on their supporting frame (Fig. 3). Make or check the following electrical interconnections:

(i) The camera synch. in plug on the control unit is connected to the flash synchronisation contacts on the camera via the existing schlieren flash source trigger wiring. (Note: Use upper set of contacts on Praktina camera).

(ii) The Unblitz shutter plug on the control unit is connected to the mechanical shutter.

(iii) The laser modulation output on the control unit is connected to the modulation input plug on the rear of the laser power supply.

(iv) The pockels cell output on the control unit is connected to the input plug on the PA 75 pulse amplifier.

(v) The high voltage output and bias plugs on the pulse amplifier are connected to the two inputs (either way around) on the PC 19 electro-optic modulator.

(d) Place laser power meter head so that it intercepts the laser output, set laser modulation potentiometer on control unit to 000 and turn laser modulation switch to "on". (Note: When changing any of the switch settings on the control unit press the test button to ensure that the control unit cycles to the desired state. The test button may fail to work if an uncocked camera is connected to the camera synch. input). Switch laser power supply mode switch to "current" and start laser (Ref. 2). Using the power supply "current adjust" knob set the laser current so that the plasma is alight but the tube is not lasing (about 10 to 15A). Adjust excitation potentiometer to give an output of about 100 mW. A power level of 100 mW or slightly less has been found to be convenient for setting up purposes since it is sufficient to make the beam easily visible even when expanded to the full system aperture but low enough to avoid damage to any of the optical components used.

N.B. POWER OUTPUTS GREATER THAN 100 mW MUST NEVER BE BLOCKED BY THE ELECTRO-OPTIC MODULATOR OR MECHANICAL SHUTTER, OR ALLOWED TO PASS THROUGH THE SPATIAL FILTER, FOR MORE THAN ABOUT 100 msec.

(e) Remove pin hole from spatial filter (it is just held in place by magnets) and remove the power meter head from the laser beam. Adjust alignment of optical components so that laser beam passes cleanly through centre of electro-optic modulator and mechanical shutter and the expanded beam from the microscope objective is centred on the hole in the side of the schlieren box.

(f) Rotate electro-optic modulator until the axis of the input polariser is aligned with the laser output polarisation. This is done by finding the position where the least light is scattered from the sides of the input polarising prism. Switch on mains and EHT switches on PA 75 pulse amplifier[3] (Fig. 8). With the pockels cell switch on the control unit in the "open" position adjust the "set bias" control on the pulse amplifier to maximise the modulator transmission. This can be most easily done by minimising the light scattered from the modulator output polariser. With the pockels cell switch on the control unit in the closed position adjust the "set output" control on the pulse amplifier to minimise modulator transmission. Check modulator on and off states and make fine adjustments if necessary. If the output supply on the pulse amplifier fails (which it does with some regularity) it is probably due to the fold back current limiting protection circuit[3] operating. This can be reset by turning the EHT switch off for a few seconds.

(g) With the pockels cell and mechanical shutter both open, insert the pin hole in the spatial filter. Adjust the pin hole location as follows: Move the pin hole further from the microscope objective than the focal plane. Place a white card on the side of the schlieren box and make X and Y adjustments to the pin hole until a small spot of light is observed. Slowly move the pin hole towards the lens with the Z micrometer while making X and Y adjustments to keep the spot visible. The adjustment is correct when an evenly illuminated expanding beam is obtained without diffraction rings. To check the focus make a small X or Y adjustment. A sharply cut off beam indicates correct focus, a slow smear indicates poor focus. If the expanding beam is not properly centred on the hole in the side of the schlieren box adjust the position of the laser slightly to recentre it.

(h) Remove the reference beam focusing lens from the source schlieren box. Adjust the additional plane mirror (Fig. 1) so that the expanding laser beam fills the existing plane mirror. Adjust the existing plane mirror so that the beam fills the collimating mirror. Check the collimation of the resulting beam by introducing a plane mirror into the beam leaving the schlieren box and observing the location of the source image formed by the reflected light. If properly collimated the source image will occur in the same plane as the pin hole. If the collimation is not satisfactory the spatial filter must be moved along the laser beam axis and the alignment procedure detailed in (g) repeated. This collimation procedure is difficult and time consuming but coincidence between pin hole and source image plane of better than 10 mm can be obtained.

(i) Adjust collimating mirror so that beam through test section fills focusing mirror in control room schlieren box. If a two dimensional model is used in the tunnel, fine adjustments to the collimating mirror will be required to align the beam with the model surface. This operation is simplified by holding a piece of white card against the various model surfaces near the test section exit window and observing the shadows and reflections.

(j) Adjust focusing mirror and two plane mirrors in control room schlieren box so that beam is centred on plane mirrors and is horizontal and directly above the optical rail which supports the camera.

(k) Place the reference beam focusing lens in the source schlieren box (Figs. 1 & 4). Adjust the lens position to bring the reference beam to a focus in the tunnel mid plane as low as possible consistent with the reference beam being captured by the focusing mirror in the receiving end schlieren box. In practice about 10 mm of the reference beam can fall below the focusing mirror without restricting the interferogram area. When correctly focused the reference beam will be circular and of equal diameter at the two test section windows. Lightly polish the test section windows at the reference beam location with a soft, clean, lint free cloth and observe the reference beam near the plenum chamber exit window with the aid of a white screen. If the reference beam illumination shows significant 'fish eyes" or other interference patterns the reference beam focusing lens should be moved slightly to place the reference beam on a (hopefully) better area of the test section windows.

(l) Place a temporary screen in the receiving schlieren box at the location of the horizontal line of the astigmatic source image formed by the test beam. Introduce the reference beam expanding lens (Figs. 2 & 5) and adjust it so that it intercepts the reference beam and forms a horizontal line image of the same length and coincident with that formed by the test beam. This matching of astigmatic aberrations in the two beams produces approximately straight fringes in the interferograms (Fig. 9). If this matching is not carried out curved fringes of highly unequal spacing result (Fig. 9) and fringe definition will be lost over some of the field of view due to the limitations of film resolution.

(m) Move the temporary screen to the rear of the receiving schlieren box (near the ground glass screen) and introduce the beam folding mirror (Figs. 2 & 5) with its leading edge adjacent to the horizontal line of the astigmatic source images. Adjust this mirror until the test and reference beams are superimposed on the temporary screen with 200 to 300 fringes across the field (Fig. 9). The fringes are somewhat difficult to see due to unsteadiness and speckle effects.

(n) Introduce the camera lens (immediately behind the trailing edge of the beam folding mirror) and the camera (with its normal lens removed) as shown in Figs. 2 & 5. To focus the camera on the tunnel test section, run the tunnel at a Mach number which will produce strong shock waves on the model and slide the camera along its rail until the shadowgraph image of the shocks is least distinct.

(o) Place power meter in front of laser, set laser modulation switch on control unit to "on" and set laser output to 1.5 watt using the laser modulation potentiometer. Switch off laser modulation and remove power meter. (N.B. It is important that high power laser outputs (> 100 mW) are never allowed to be blocked by the electro-optic modulator or mechanical shutter, or allowed to pass through the spatial filter, for more than about 100 msec.) Put all control switches on control unit in down position (Fig. 8), place pockels cell time switch to 5 μsec, connect flash sync. cable to camera and set camera shutter speed to 1/10 sec. The interferometer should now be ready for operation. To check the laser control system; remove the camera back, place a piece of tracing paper in the film plane, cock and release shutter. The whole film area should be illuminated by a clearly visible green flash.

(p) Make some test exposures (using Ilford FP-4 film) to arrive at the optimum number of fringes i.e. the maximum number obtainable with acceptable contrast. The number of fringes is increased by raising the leading edge of the beam folding mirror and reduced by lowering it. This adjustment is quite sensitive and steps of half a flat of the nuts should be used.

4. OPERATING PROCEDURE

Once set up as described in the previous section the interferometer is very stable. However it is suggested that the following checks be carried out at the start of each day of testing:

(a) With laser modulation "off" check that plasma is alight (laser is drawing current) and that it is not lasing.

(b) Adjust laser modulation potentiometer to give an output of about 100 mW and check electro-optic modulator transmission and extinction and spatial filter pin hole adjustment.

(c) Check centring of spatial filter output beam on hole in side of schlieren box. If the beam has drifted excessively it can be moved back with small adjustments of the laser supporting feet or the laser back mirror.

(d) With laser modulation "on" reset power to desired value (≈ 1.5 watt). Turn modulation "off" before removing power meter head.

In addition to the above points a continuous check should be maintained on the laser cooling water flow and the filter element replaced when necessary.

The actual operation of the interferometer consists of simply loading the camera with film and operating the shutter when required. A check on the laser operation can be maintained by watching the light scattered from the ground edge of the reference beam expanding lens. During the operation of the interferometer the schlieren box should not be touched, and if disturbed accidently it should be left for about 30 sec. to settle down before making the next exposure. A flexible shutter release must be used to minimise the disturbance caused by camera operation.

A "no flow" interferogram should be taken immediately before and after each run. When these two no flow interferograms are superimposed (using the edges of the exposed portion of the film for alignment, not the edge of the film strip) there should be no more than two composite fringes covering the field. If an excessive number of fringes are observed, the entire run should be discarded since some part of the interferometer has been moved during the course of the run.

To make prints of the composite interferograms it is suggested that two separate exposures of the "with flow" and "no flow" interferogram negatives be superimposed on a single sheet of high contrast (Ilfospeed grade 5) paper. The two images must be aligned using the edges of the exposed film area not the model image which is usually somewhat blurred. The enlarger red filter can be used during image alignment and appropriate reference marks made on the paper using a biro. The enlarger height and focus adjustments must not be touched between exposures. To produce the best contrast very accurate enlarger exposure control is required. Exposure changes of about 10% have a marked effect on the results.

Photocopying has been found to have a powerful contrast enhancing effect on interferograms. If this technique is used the original enlargement should be somewhat on the light side.

5. NOTES ON INTERFEROMETER SENSITIVITY

The fringe shift (δN) obtained from a reference beam interferometer such as the present instrument is given by[4]

$$\delta N = \int_0^b \frac{k}{\lambda} (\rho - \rho_{ref}) \, dy \qquad (1)$$

where k = Gladstone-Date constant

λ = Wavelength of light used

ρ = Test section density

ρ_{ref} = Effective density in reference beam (regarded as a constant for all rays in reference beam)

y = Cross stream co-ordinate

b = Tunnel width.

The wavelengths obtainable from the Argon ion laser vary by only about 12%. Therefore, unless a totally different type of laser is used, the fringe shifts obtained are simply related to the differences between test beam and reference beam densities. In the present interferometer design the absolute fringe shift given by Eqn. (1) is not measured directly and is not particularly relevant. What is more important from the point of view of interferogram analysis is the total number of fringes in the field of the final composite interferogram. It can be shown[4,5] from Eqn. (1) that for a two dimensional model the total number of fringes is directly proportional to the difference between the maximum and minimum densities in the test beam and independent of the model scale (the model span being constant). For a general three dimensional model the total number of fringes will be approximately proportional to the difference between the maximum and minimum densities occurring in the flow and directly proportional to the model scale.

The relationship between the maximum density difference and the test conditions will be developed below.

For compressible isentropic flow·

$$\frac{\rho}{\rho_o} = \left[1 + \frac{\gamma - 1}{2} M^2\right]^{\frac{-1}{\gamma-1}} \qquad (2)$$

where ρ = Density

M = Mach number

γ = Ratio of specific heats (1.4 for air)

subscript o = stagnation conditions.

Noting that the maximum flow density will occur at the stagnation point, the maximum density difference may be written as:

$$\rho_o - \rho_{min} = \rho_o \left[1 - \left(1 + \frac{\gamma-1}{2} M_{max}^2\right)^{\frac{-1}{\gamma-1}} \right] \qquad (3)$$

Assuming the Prandtl-Glauert form of the subsonic compressible similarity rule:

$$M_{max}^2 = M_{fs}^2 \left[1 - \frac{C_{pi}}{\sqrt{1-M_{fs}^2}} \left(1 + \frac{\gamma-1}{\gamma} M_{fs}^2\right) \right] \qquad (4)$$

where C_{pi} = Minimum incompressible pressure coefficient

Subscript **fs** = Free stream value

" max = Maximum value.

It is known that the maximum Mach number occurring in a subsonic free stream flow is limited to about 1.4 by the occurrence of shock waves. When Eqn. 4 yields a value of M_{max} greater than this the value, 1.4 should be used in its place. The result of evaluating equations (3) and (4) is presented in Fig. 10.

A typical pair of two and three dimensional interferograms are presented in Figs. 11 and 12 respectively. Both models have shock waves present so the total number of fringes in each interferogram is at its maximum value for the particular tunnel operating pressure. Using Figs. 10 to 12 it should be possible to estimate the number of fringes resulting from any proposed test. In general the interferometer sensitivity is well matched to the transonic wind tunnel operating envelope with the exception that small bodies of revolution tend to produce too few fringes except at the higher Mach numbers. The foregoing analysis has concentrated on subsonic free stream Mach numbers. However the interferometer is not limited to subsonic operation and similar numbers of fringes are obtained at low supersonic and high subsonic speeds.

6. INTERFEROGRAM ANALYSIS

It is possible, but very time consuming and difficult, to analyse general three dimensional flow fields using interferometry. This operation requires taking a number of interferograms with different directions of view, digitising the interferograms and performing a quite complex computer analysis[5,6]. Regions of the flow that are hidden by the model (e.g. wing body junctions) obviously cannot be analysed.

The analysis of flows around bodies of revolution at zero incidence is considerably simpler. Only one interferogram is required and the conditions at any point in the flow can be obtained from a relatively simple integral. However the problem of digitising the interferogram for entry into the computer remains.

The analysis of two dimensional flows over aerofoil sections completely spanning the tunnel is very simple and does not require the use of a computer. The vast majority of quantitative interferometric work has been, and will probably remain, two dimensional. The fringes in two dimensional interferograms are lines of constant density and thus constant pressure in isentropic flow. The basic expression for the analysis of two dimensional isentropic flows is[4]:

$$\frac{P}{H} = \left[\left(\frac{P_r}{H}\right)^{1/\gamma} + \frac{\lambda R T_o}{KLH} . N\right]^{\gamma} \tag{5}$$

where P = Static pressure at any point

H = Tunnel stagnation pressure

P_r = Reference pressure

T_o = Tunnel stagnation temperature

L = Tunnel width

R = Gas constant

k = Gladstone-Date constant

λ = Wavelength of light used

γ = Ratio of specific heats

N = Fringe number where P is requird (P_r is the pressure associated with fringe 0)

There are two approaches to evaluating Eqn. 5 depending on whether or not the model has pressure tappings.

(i) If the model is not pressure tapped the pressure associated with some arbitrary fringe (which will be taken as fringe 0) can be measured with a small static pressure probe. Alternatively a fringe which appears to vanish off to infinity and not loop back to the model can be used as the reference fringe and assumed to correspond to free stream pressure. The value of L used should be somewhat less than the geometric tunnel width due to the presence of the sidewall boundary layers.

(ii) If the model is pressure tapped (even sparsely) a fringe that cleanly meets the surface can be selected as the reference fringe and its pressure obtained by interpolating the surface pressure readings. The effective value of the term $\frac{\lambda RT_0}{KLH}$ can be obtained from the number of fringes meeting the surface between two points of known pressures with a monotonic pressure change between them. This avoids the uncertainty as to the correct value of L.

Which ever of the above methods is adopted, the problem remains of identifying the fringe number at the point where the pressure is required. In general the procedure is to count from fringe 0, the only decision required is whether the next fringe is of higher or lower order (higher or lower pressure). Normally this will be self evident from the known physics of the flow but in doubtful cases the information can be obtained from the raw "with-flow" interferogram. In regions of streamwise compression the fringes slope upwards and in regions of expansion slope downwards (Fig. 13). Shock waves tend to divide up the flow into distinct regions. If the shock is not too tall it is possible to trace a continuous fringe over the top of the shock (Fig. 11) and thus link the fringe numbering in the two regions. If the shock extends outside the field of view it is necessary to identify separate reference fringes in each region.

Ref. 4 contains much useful information on interferogram analysis and factors affecting the accuracy of interferometric results.

7. CONCLUSION

The setting up and operation of the transonic wind tunnel laser interferometer is described in detail. Notes on the range of application of the interferometer and interferogram analysis are also included.

It is intended that this publication along with Ref. 1 provides sufficient information to permit an aerodynamicist without optical experience to successfully use the instrument.

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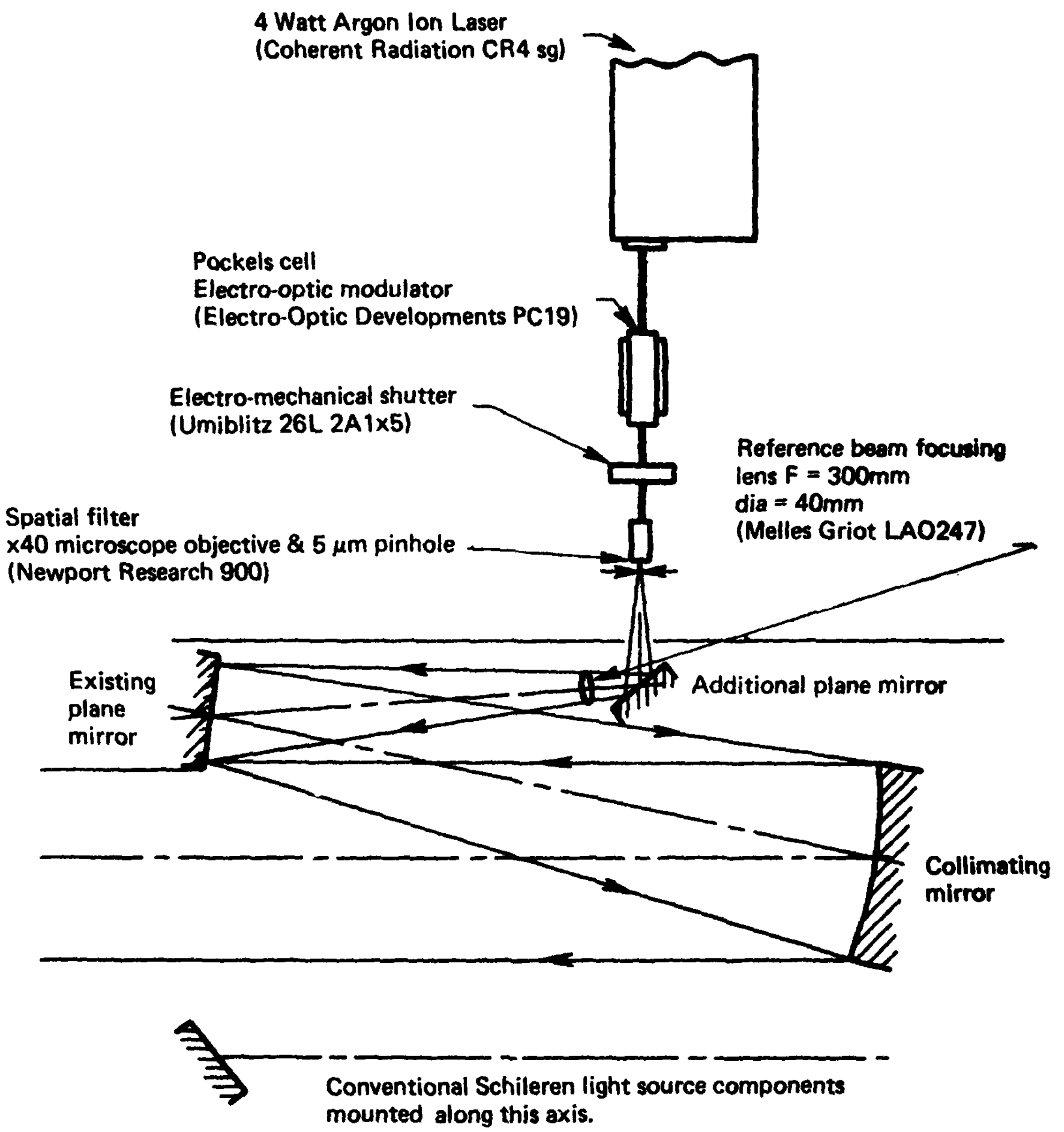


FIG. 1 ARRANGEMENT OF SOURCE END OF INTERFEROMETER

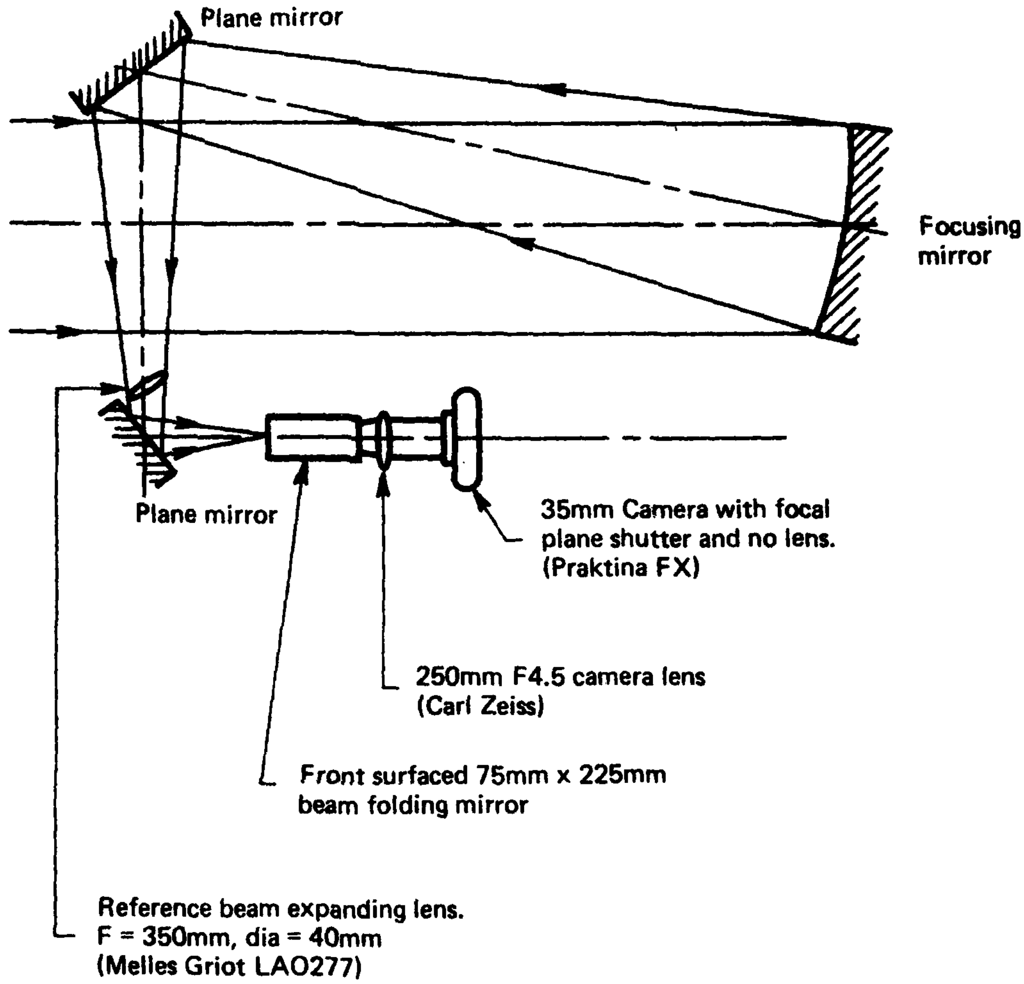


FIG. 2 ARRANGEMENT OF RECEIVING END OF INTERFEROMETER

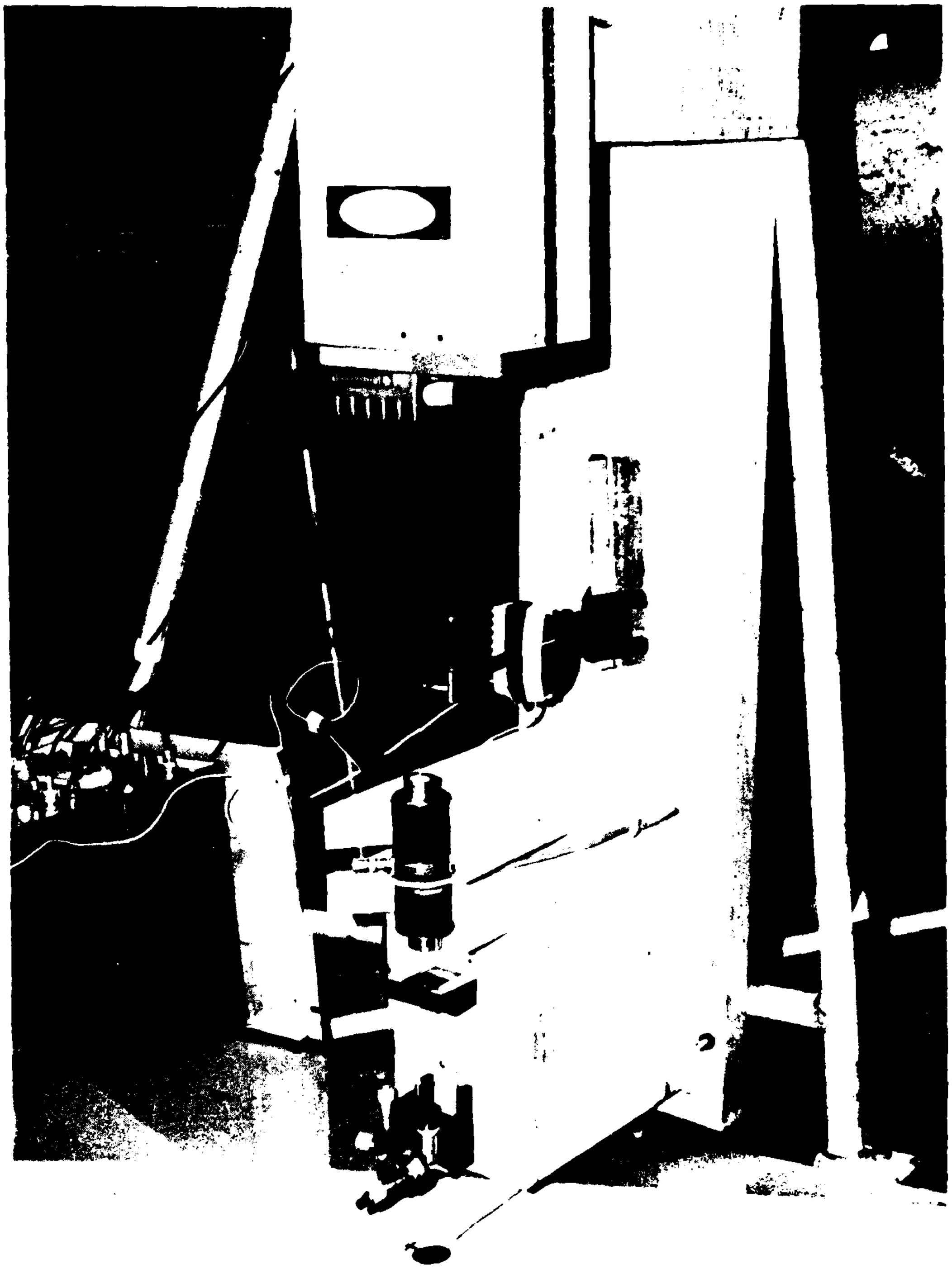


FIG. 3 PHOTOGRAPH OF INTERFEROMETER COMPONENTS MOUNTED OUTSIDE SOURCE SCHLIEREN BOX. (Viewed from above)

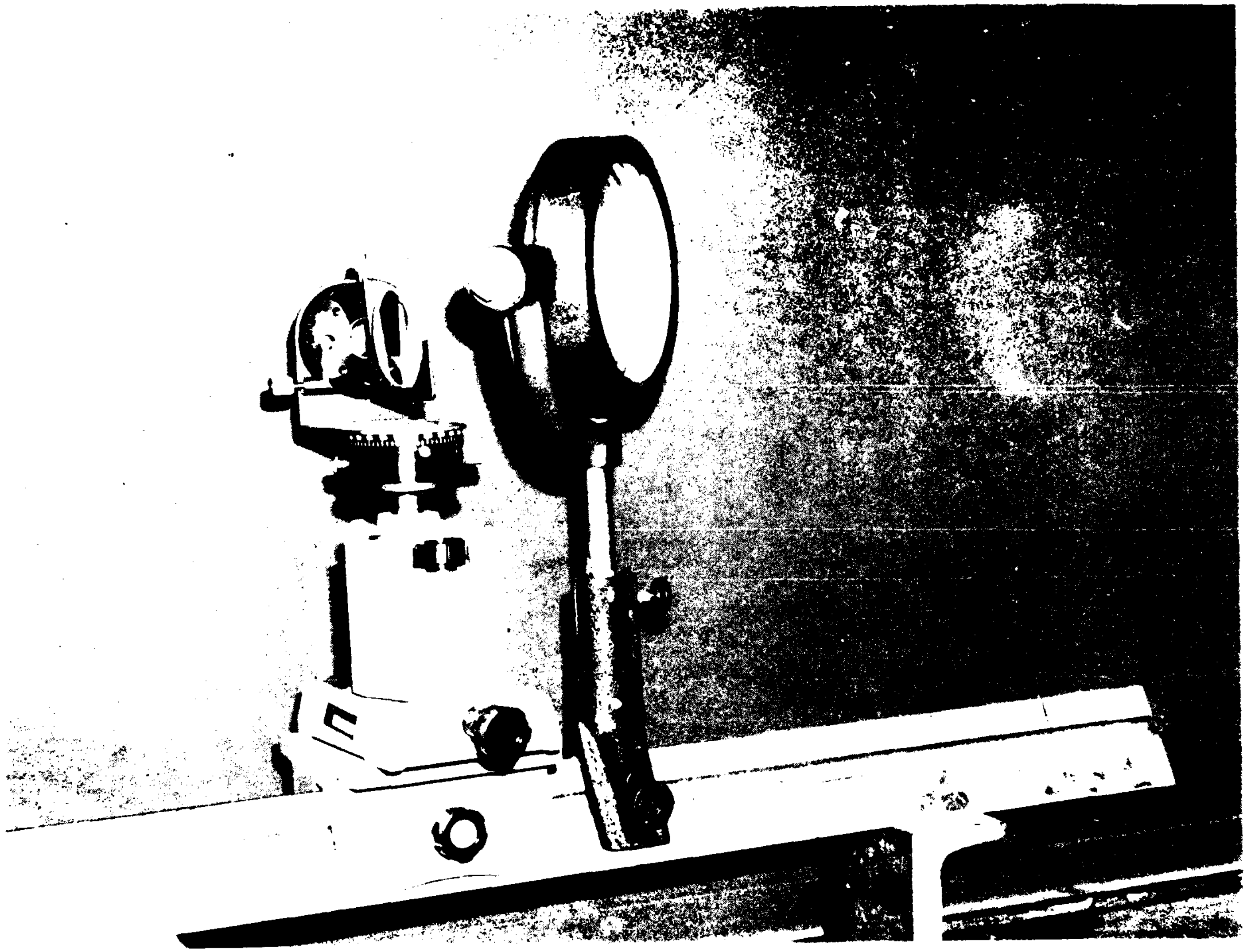


FIG. 4 PHOTOGRAPH OF INTERFEROMETER COMPONENTS MOUNTED INSIDE SOURCE SCHLIEREN BOX.

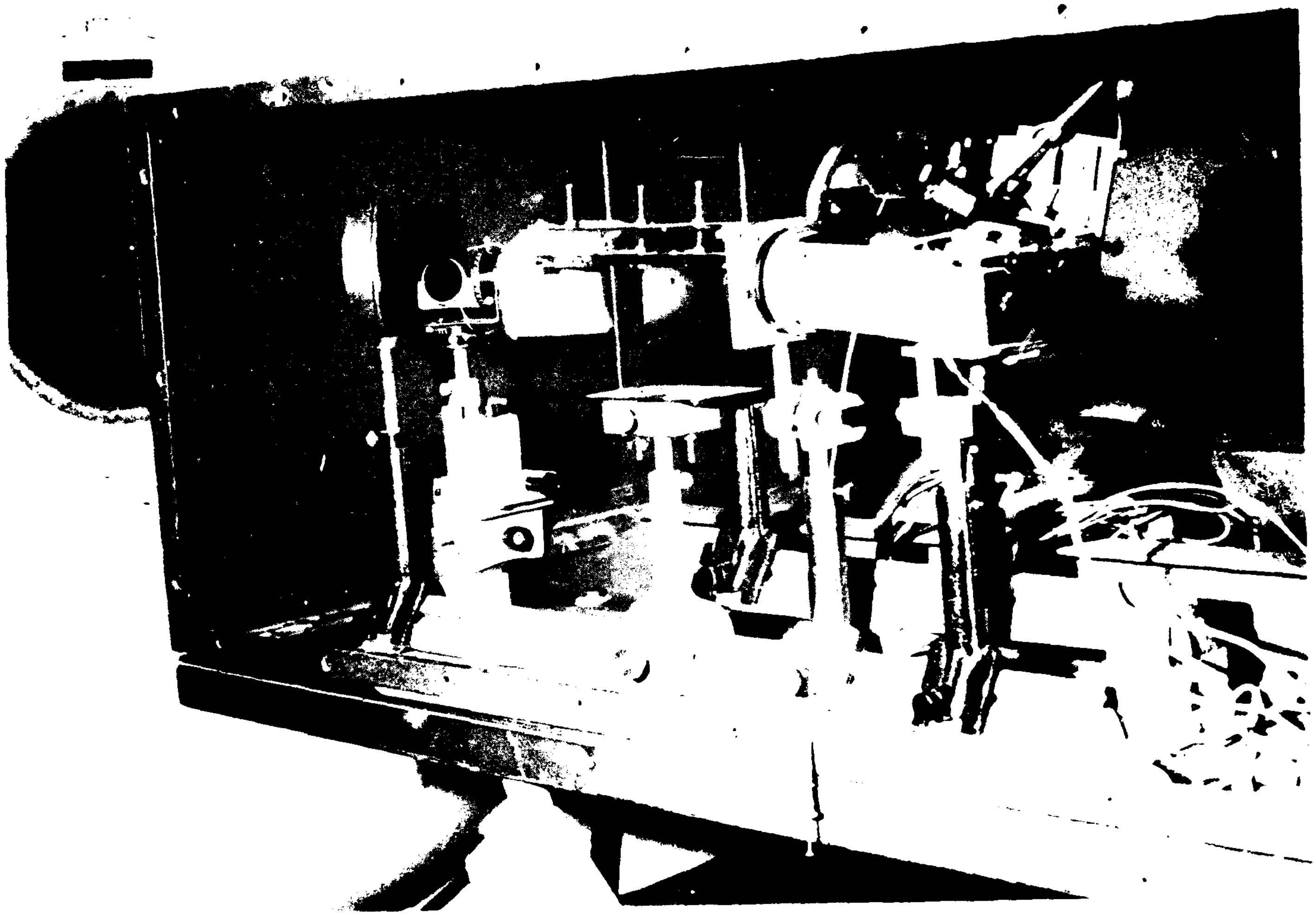
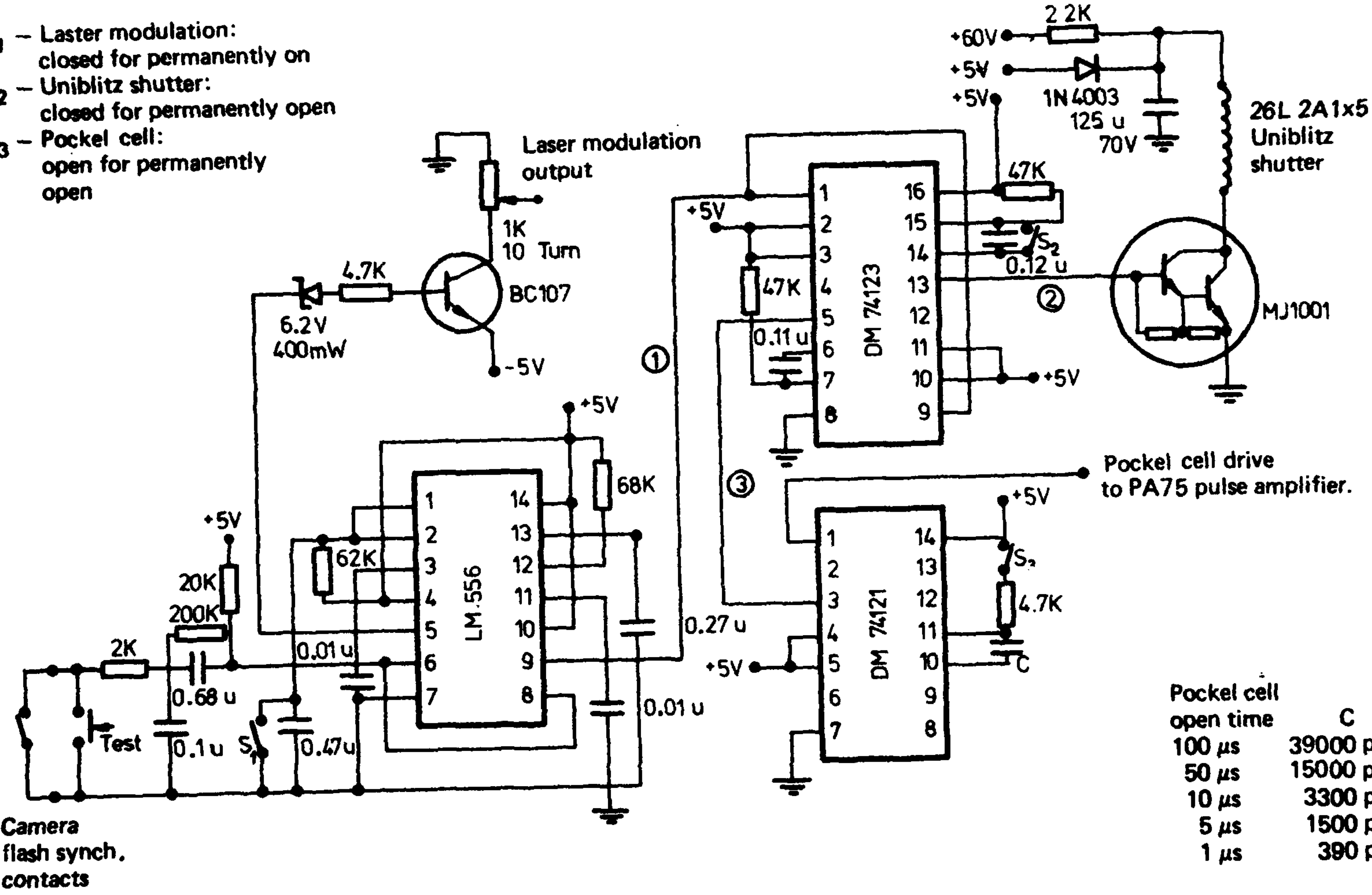


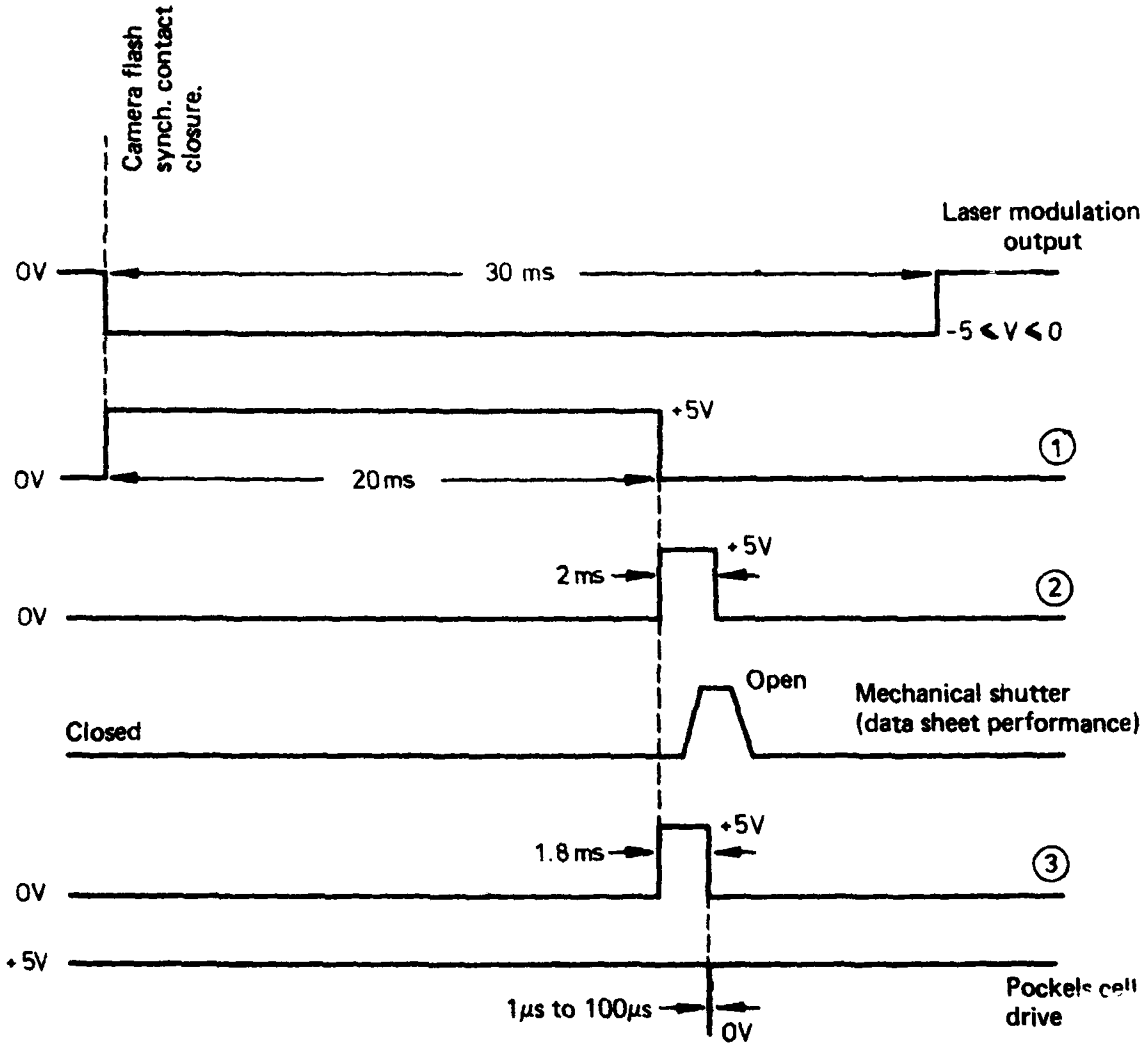
FIG. 5 PHOTOGRAPH OF INTERFEROMETER COMPONENTS MOUNTED INSIDE RECEIVING SCHLIEREN BOX.

S_1 – Laster modulation:
closed for permanently on
S_2 – Uniblitz shutter:
closed for permanently open
S_3 – Pockel cell:
open for permanently
open



Pockel cell open time	C
100 µs	39000 pF
50 µs	15000 pF
10 µs	3300 pF
5 µs	1500 pF
1 µs	390 pF

FIG. 6 CIRCUIT DIAGRAM OF LASER INTERFEROMETER CONTROL UNIT.



For location of points 1, 2 & 3 see Fig. 6.

FIG. 7 TIMING DIAGRAM FOR INTERFEROMETER CONTROL UNIT

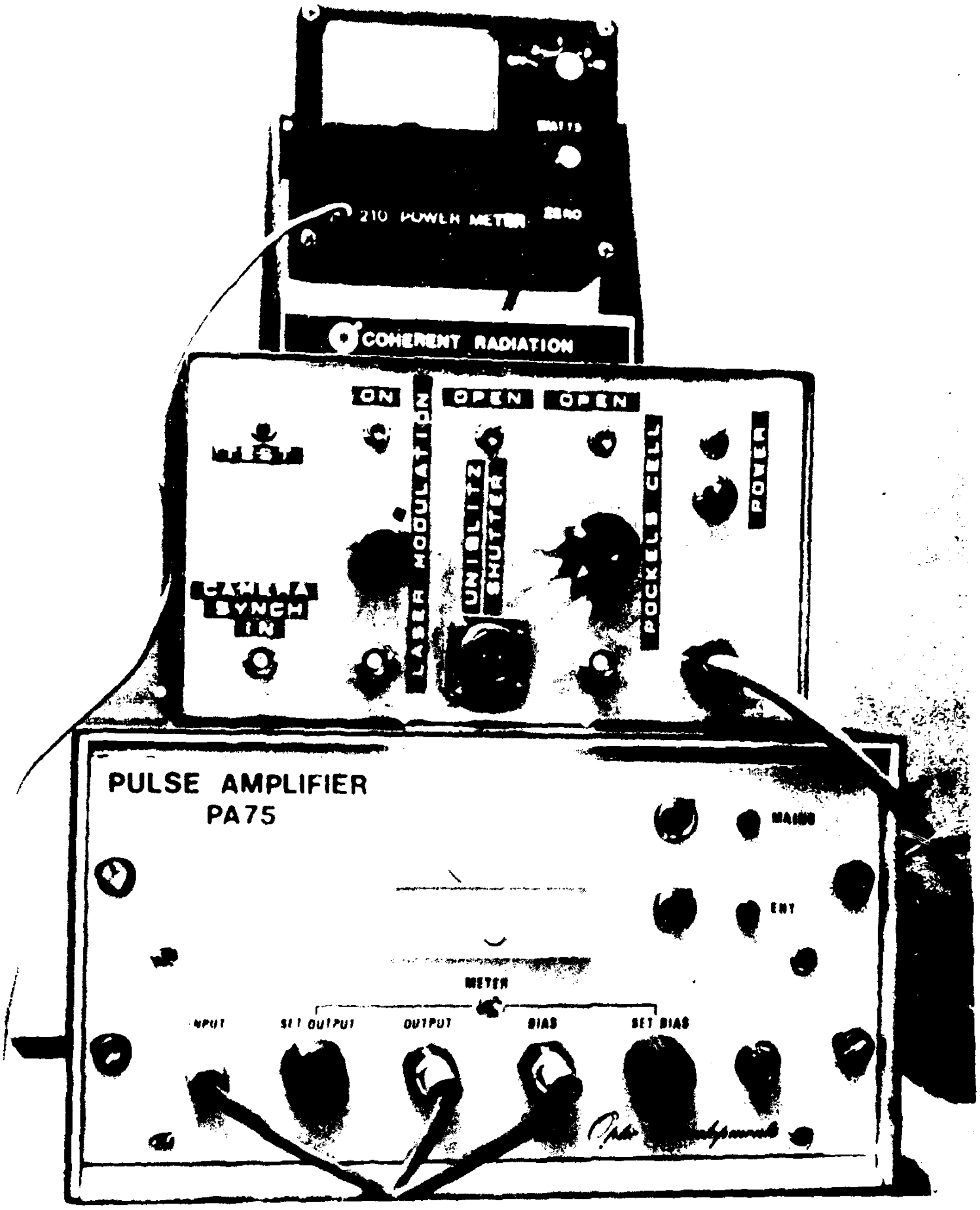
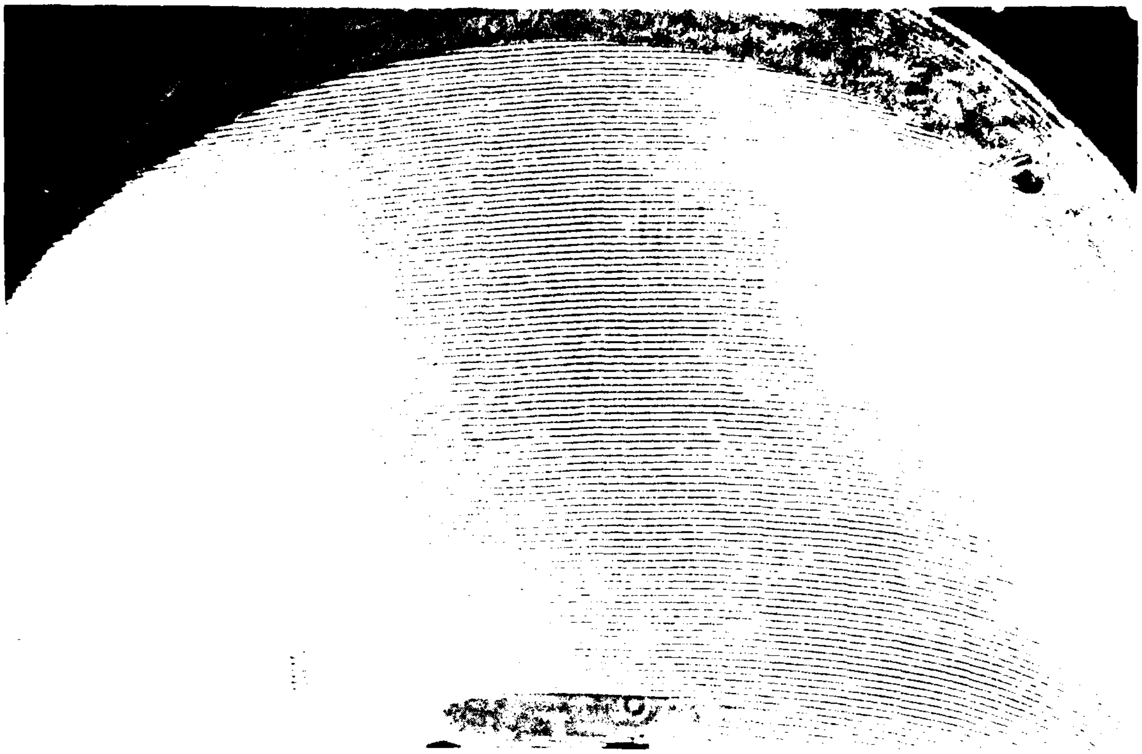


FIG. 8 PHOTOGRAPH OF POWER METER, CONTROL UNIT AND PULSE AMPLIFIER



Test and reference beam astigmatism matched.

Test and reference beam astigmatism not matched.

FIG. 9 NO FLOW INTERFEROGRAMS.

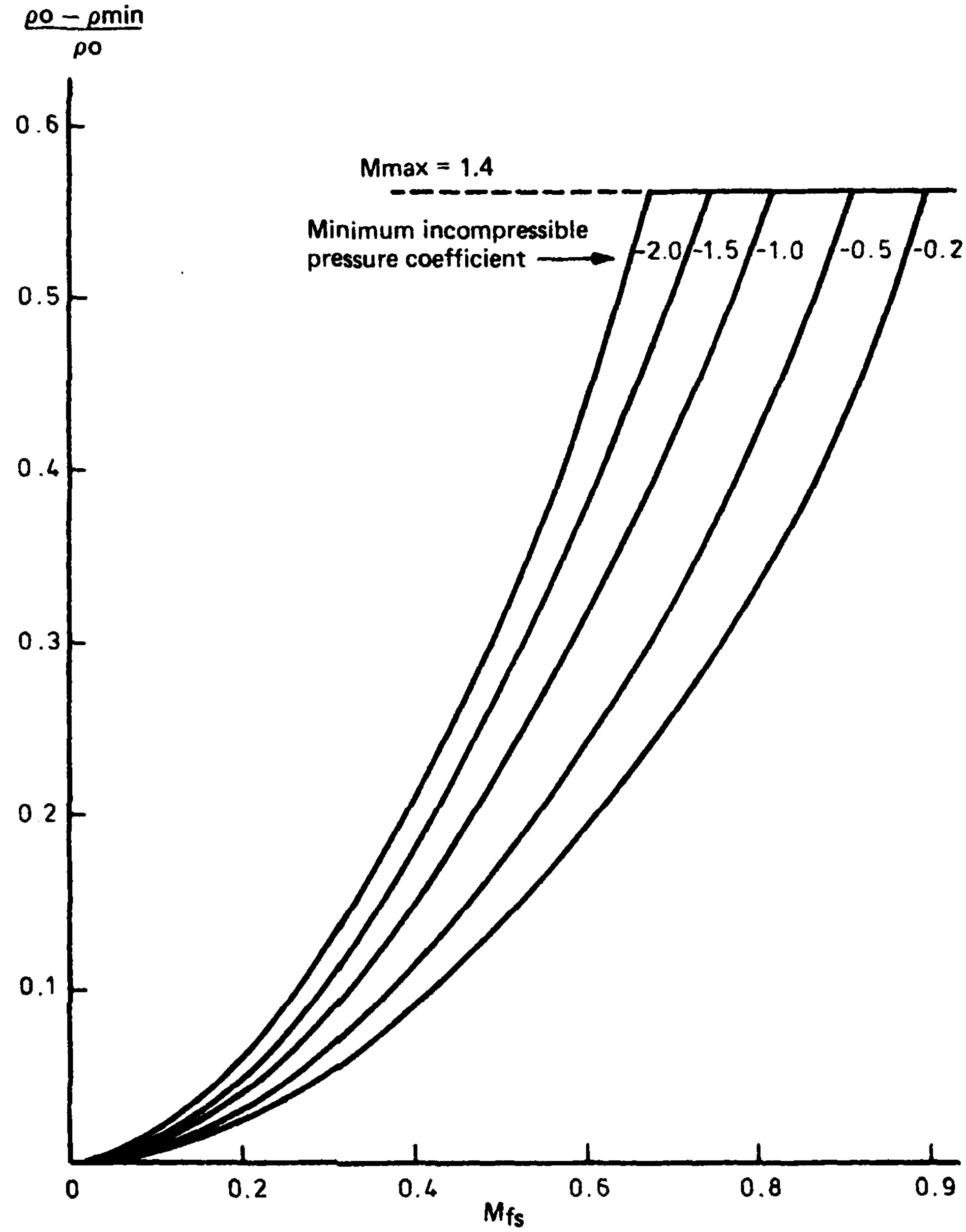


FIG. 10 VARIATION OF $\frac{\rho o - \rho min}{\rho o}$ WITH M_{FS}

FIG. 11 INTERFEROGRAM OF FLOW OVER UPPER SURFACE OF SUPERCRITICAL AEROFOIL BGK–1
Mach number = 0.85, Incidence = 14^{o}, Total pressure = 16.8 inches Hg.

FIG. 12 INTERFEROGRAM OF FLOW OVER 51MM DIAMETER CONE–CYLINDER MODEL.
Mach number = 0.90, Incidence = 0^{0}, Total pressure = 14.7 inches Hg.

FIG. 13 "WITH FLOW" INTERFEROGRAM OF FLOW OVER UPPER SURFACE OF SUPERCRITICAL AEROFOIL BGK–1.
Mach number = 0.85, Incidence = 1.4°, Total pressure = 16.8 inches Hg.

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